DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
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FATIGUE OF CABLE ANCHORAGES ON A CABLE-STAYED BRIDGE

By

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Mine
my copy

This piece of work is dedicated to my lovely family:

Ayah, thank you for everything and being always there for me,
Ibu, thank you for being strong for me,
Kak Yong and Dik Afiq, thank you for being understanding,

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ABSTRACT

Studies have shown that the connection details used for cable anchorage blocks on cable-stayed bridges have the potential for fatigue damage due to fluctuating stresses generated by the cyclic traffic loads passing over the bridge. To investigate the fatigue damage and determine the remaining fatigue life of a cable anchorage block used on a cable-stayed bridge, finite element (FE) analyses were undertaken by using the Fatigue Load Model 4 (FLM 4) proposed by the Eurocodes to identify the most fatigue-critical locations within the details.

One of the main objectives of this research was to identify the critical area prone to fatigue in the anchorage block due to the response in traffic loads. Therefore, two types of numerical models of a typical cable anchorage block were analysed as a three dimensional sub-model which was driven by global cable forces obtained from the global analysis of a three-span cable-stayed bridge. These models are of the cable anchorage block without the longitudinal girder modelled and the cable anchorage block with the longitudinal girder modelled. The cable anchorage blocks without the longitudinal girder model were classified into three categories of model types namely; model types 0, A and B. Similarly, the cable anchorage blocks with the longitudinal girder model were classified as model types A-G, B-G and C-G. These model classifications are based on several boundary conditions simulated in the analyses. In addition to this, the fatigue behaviour of the cable anchorage block was analysed by using three different approaches namely; by using the nodal stresses at the location of the stress concentration (node stress concentration), by using a stress averaged over an area in the vicinity of the stress concentration (average elements) and by using the hot-spot method, in order to identify the stress ranges that adversely affect the remaining fatigue life of cable anchorages.Each approach was analysed with three different mesh sizes; 5mm by 5mm, 10mm by 10mm and 20mm by20mm in order to carry out a mesh sensitivity analysis of the resulting stresses and associated stress ranges. The 10mm by 10mm mesh size wasfound to be most appropriate for this fatigue appraisal. This finding is supported because the 10mm by 10mm mesh size is specified in several code of practices such as the International Institute of Welding (IIW) and BS 7608 as guidance for use when determining hot-spot stress when using the hot-spot method for the fatigue analyses of a welded detail.

The critical stresses from model type C-G were used in the fatigue appraisal as the behaviour of this model represented more accurately the actual cable anchorage block on the cable-stayed bridge compared to the other types of models used. Model type C-G were selected for further fatigue appraisal as this model include the correct boundary conditions and applied load that represented the actual condition of the anchorage behaviour on the cable-stayed bridge. This included the movement of the top anchorage block due to the displacement of the cable and in addition the deck movement. Also, non-uniform pressure was applied on the bearing plate which was included to model possible construction tolerances which was one of the important properties of the model type C-G. In evaluating the possible fatigue damage in the cable anchorage block, the cumulative model for fatigue failure expressed in terms of Miner's rule was used. In addition to this, the condition of the structural detail due to fatigue with increasing traffic loading was determined by projecting traffic volume increases of up to 20%. Based on the results calculated, if the *long distance* traffic characteristic was used in fatigue appraisal, the cable anchorage block was justified to be not 'safe' as the damage accumulation for fatigue, D_d at the top gusset was recorded as 1.270, which exceeded the limiting value of 1.0 corresponding to a 120 year design life. However, if *medium distance* traffic characteristic was used in the fatigue appraisal, the cable anchorage block will remain 'safe' except when a 20% increase in traffic volume was included in the analysis, which resulted in D_d value of 1.016. Also, if a more conservative value of $D_d = 0.5$ as suggested by IIW (2008) was used, the cable anchorage block appraised by using both the *long distance* and *medium distance traffics* was found not safe from fatigue damage and would not survive its *design working life* without structural repair. For future fatigue appraisals of anchorage blocks (and other important structural details), it is strongly recommended that the numerical model of anchorage block is analysed together with the longitudinal girder using the hot-spot method. A 10mm by 10mm finite element mesh size is suggested and it is also necessary to specify the displacement at the top of the anchorage block to simulate the cable movement together with the girder movement both of which are obtained from the global analysis of the whole bridge structure.

AUTHOR'S DECLARATION

This thesis and the work to which it refers are the results of my own efforts. Any ideas,data, images or text resulting from the work of others (whether published or unpublished)are fully identified as such within the work and attributed to their originator in the text,bibliography or in footnotes. This thesis has not been submitted in whole or in part for anyother academic degree or professional qualification. I agree that the University has the rightto submit my work to the plagiarism detection service TurnitinUK for originality checks.Whether or not drafts have been so-assessed, the University reserves the right to require anelectronic version of the final document (as submitted) for assessment as above.

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ABBREVIATIONS AND SYMBOLS

LIST OF ABBREVIATIONS:

AASHTO	American Association of State Highway and Transportation Official
AASHTO-LRFD	American Association of State Highway and Transportation Official – Load and Resistance Factor Design
ADTT	Average Daily Truck Traffic
$ADTT_{SL}$	Single-lane Average Daily Truck Traffic
ALLPD	Energy dissipated by rate-independent and rate-dependent Plastic Deformation
ALLSE	Recoverable Strain Energy
BS	British Standards
AT	Anchorage Tube
CA	Constant Amplitude
CAFL	Constant Amplitude Fatigue Limit
DAF	Dynamic Amplification Factor
DOF	Degree of Freedom
DWL	Design Working Life
E-TOTAL	Total Energy Balance
FCGR	Fatigue Crack Growth Ratio
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
FLM	Fatigue Load Model
FRP	Fibre Reinforced Polymers
HAZ	Heat Affected Zone
HDPE	High Density Polyethylene

HGV	Heavy Good Vehicle
HiAM	High Amplitude
HSM	Hot-Spot Method
LEFM	Linear Elastic Fracture Mechanics
LSA	Linear Static Analysis
MBP	Minimum Breaking Point
New PWS	New Parallel Wire Strand
OL	Overloading
PWS	Parallel Wire Strand
RMS	Root-mean-square
SCF	Stress Concentration Factor
SLS	Serviceability Limit State
SS	Structural Steel
SFV	Standard Fatigue Vehicle
TS	Tandem System
UDL	Uniform Design Load
UL	Under-loading
ULS	Ultimate Limit State
UTS	Ultimate Tensile Strength
VA	Variable Amplitude
VAL	Variable Amplitude Loading
VAFL	Variable Amplitude Fatigue Limit
WIM	Weight-In-Motion

LIST OF SYMBOLS:

a / α	Crack length
D / D_d	Accumulation of fatigue damage
E	Modulus of elasticity / Young's Modulus
e	Width of the elliptical crack
G	Shear modulus
i	Initial, or Integer
K	Stress intensity factor
K_C	Fracture toughness
K_t	Stress concentration factor
m	S-N curve slope
N	Number of repetitions to failure
n	Number of cycles
N_i	Endurance cycles
N_i / N_R	endurance cycles obtained for a stress range specified details measured
N_{obs}	number of observation of heavy vehicles
n_i	number of cycles associated at the particular damaging stress range
Q_{ik}	Tandem system
q_{ik}	Uniform design load
R	Load ratio
S-N	Stress – Number of cycles to failure
S_r	Stress range
S_m	Mean stress
S_{max}	Maximum stress
S_{min}	Minimum stress
S_{net}	Average stress
S_p	Peak stress
S_y or f_y	Yield point
Y	Dimensionless factor depending on the geometry of the specimen or structural component
σ	Stress
σ_{true}	True stress
σ_{nom}	Nominal stress

σ_{hs}	Hot-spot stress
$\Delta\sigma_c$	Allowable stress for detail category of welded
da	Variation of crack
dN	Variation of cycle endurance
$\Delta\sigma_i$ / $\Delta\sigma_R$	Stress range
$\Delta\sigma_L$	Cut-off limit in S-N Curve
$\Delta\sigma_D$	Constant Amplitude Fatigue limit in S-N Curve
ε_{nom}	Nominal strain
ε_{true}	True strain
υ	Poisson's ratio
γ	Density
γ_{eq}	Equivalent density
ΔK_{th}	Fatigue crack propagation threshold
γ_{Mf}	Safety factor of fatigue strength
γ_{Ff}	Safety factor of safe life design
λ	Damage equivalent factors
$(\Delta F)_n$	Nominal fatigue resistance

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